MULTIMEDIA UNIVERSITY

STUDENT ID NO

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# MULTIMEDIA UNIVERSITY

# FINAL EXAMINATION

**TRIMESTER 2, 2015/2016**

## EOP2016 – FUNDAMENTALS OF OPTICS

( OPE )

10 MARCH 2016
2:30pm – 4:30pm
( 2 Hours )

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**INSTRUCTIONS TO STUDENTS**

1. This Question paper consists of 6 pages with 5 Questions only.

2. Attempt **FIVE** out of **FIVE** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please print all your answers in the Answer Booklet provided.

## Question 1

(a) "All the 50 years of conscious brooding have brought me no closer to the answer to the question: What are light quanta?" – Albert Einstein.

i. Describe photon and state how its energy can be calculated.

[2 marks]

ii. Describe the principle of duality of light. Use examples in your description.

[6 marks]

(b) Mirage is one type of optical phenomena that we can observe in our daily lives. With help of a sketch, show how this phenomenon can happen.

[6 marks]

(c) Using energy diagram, explain how light can be absorbed and emitted.

[6 marks]

## Question 2

(a) Compare **three** different characteristics of virtual and real images.

[6 marks]

(b) Consider a concave mirror that produces a virtual image that is 4 times as tall as the object.

i. If the object is 30 cm in front of the mirror, what is the image distance?

[2 marks]

ii. What is the focal length of this mirror?

[2 marks]

(c) A converging lens with a focal length of 6 cm forms a 1.2 cm tall image of a 3 mm tall real object that is to the left of the lens. If the image formed is erect, find the locations of the object and the image and determine whether the image is real or virtual.

[5 marks]

(d) Figure Q2-(d) shows a simple translation of the ray in a homogeneous medium where $y_0$ and $y_1$ are positions and $\alpha_0$ and $\alpha_1$ are angles. Determine its 2 x 2 ray-transfer matrix.

[5 marks]

**Continued...**

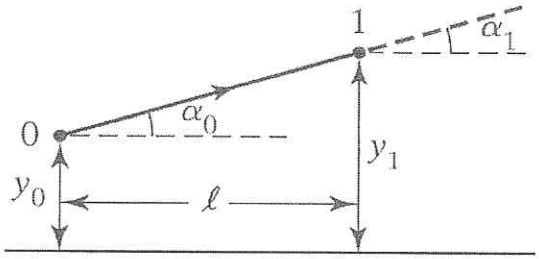



Figure Q2-(d)

## Question 3

(a) A harmonic wave traveling in the $+x$-direction has, at $t=0$, a displacement of 13 units at $x=0$ and a displacement of -7.5 units at $x=3\lambda/4$. Write the equation for the wave at $t=0$.

[8 marks]

(b) Consider the far-field diffraction pattern of a single slit of width 2 μm when illuminated normally by a collimated beam of 550 nm light. Determine the ratio $I/I_0$ at a point making an angle of $\theta = 5°$.

[5 marks]

(c) A laser beam of radius 2 mm carries a power of 5 kW. Determine:

i. its average irradiance and

[3 marks]

ii. the amplitude of its $E$ and $B$ fields.

[4 marks]

## Question 4

(a) Find the state of polarized light after passing in turn through (a) a half-wave plate with slow axis at 45°; (b) a linear polarizer with transmission axis at 45°; (c) a quarter-wave plate with slow axis horizontal. Assume the original light to be linearly polarized vertically. Use the matrix approach and analyze the final Jones vector to describe the product light. (Hint: First find the effect of the half-wave plate alone on the incident light. Summary of Jones Vectors is given at the end of the question paper)

[8 marks]

(b) Describe *Brewster*'s angle and explain what happens when we shine light on a reflecting surface at this angle.

[3 marks]

**Continued...**

(c) Derive the equation for the output intensity after polarizer 3 in figure Q4-(c) and plot the variation of the output as a function of angle $\theta$ of polarizer 2.

[9 marks]

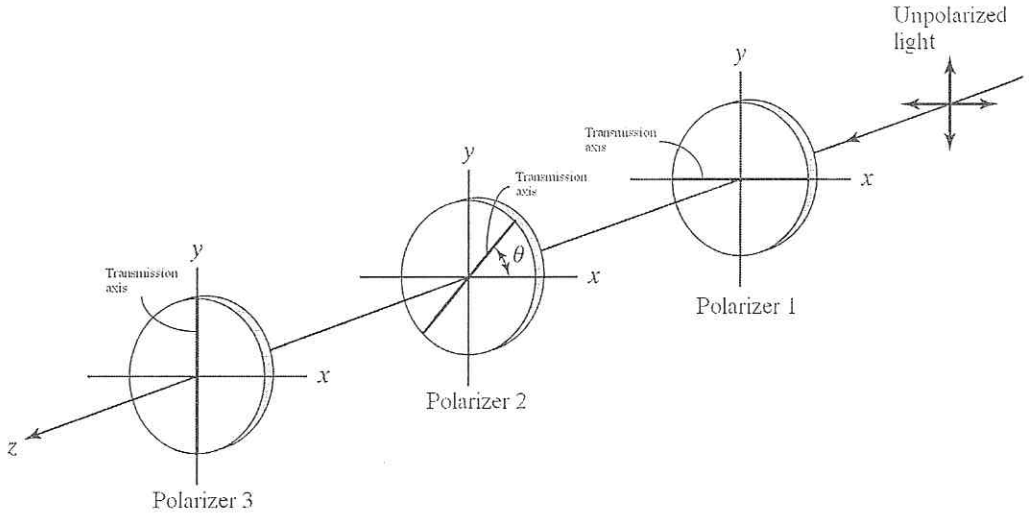



Figure Q4-(c)

## Question 5

(a) Describe the typical material selection and mechanism used to create the acoustic wave in an acousto-optic device. Support your answer with a diagram.

[5 marks]

(b) In what kind of media are both longitudinal Pockels and Kerr effects present? Compare the relative strength of these two effects by calculating the ratio of retardations produced by an appropriately applied 10 kV voltage. Derive an expression for this ratio. Then do a numerical calculation by using values of r = 10 pm/V, K = 1 pm/V$^2$, L = 2 cm, d = 1 cm and $n_0 = 2$. Use $\lambda = 550$ nm.

[6 marks]

(c) What acoustic frequency is required of a plane acoustic wave, launched in an acousto-optic material, so that a He-Ne laser beam is deflected by 1°? The speed of sound in the crystal is 2500 m/s and its refractive index at 632.8nm is 1.6.

[4 marks]

(d) Calculate the length of a Kerr cell using carbon disulfide required to produce half-wave retardation for an applied voltage of 30 kV. The electrodes of the cell have separation of 1.5 cm. Comment on the practicality of this cell.

[5 marks]

**Continued...**

## Appendix A

Physical Constants and Units

| Constant | Symbol | Value (mks units) |
|---|---|---|
| Speed of light in vacuum | $c$ | $3 \times 10^{8}$ m/s |
| Electron charge | $q$ | $1.602 \times 10^{-19}$ C |
| Boltzmann's constant | $k_B$ | $1.38 \times 10^{-23}$ J/K |
| Permittivity of free space | $\varepsilon_0$ | $8.8542 \times 10^{-12}$ F/m |
| Permeability of free space | $\mu_0$ | $4\pi \times 10^{-7}$ N/A$^2$ |
| Electron volt | eV | $1\ \text{eV} = 1.602 \times 10^{-19}$ J |
| Planck's constant | $h$ | $6.626 \times 10^{-34}$ J·s |

Summary of Jones Matrices

**I. Linear polarizers**

TA horizontal $\begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$ TA vertical $\begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$ TA at 45° to horizontal $\frac{1}{2}\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$

**II. Phase retarders**

General $\begin{bmatrix} e^{i\varepsilon_x} & 0 \\ 0 & e^{i\varepsilon_y} \end{bmatrix}$

QWP, SA vertical $e^{-i\pi/4}\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$ QWP, SA horizontal $e^{i\pi/4}\begin{bmatrix} 1 & 0 \\ 0 & -i \end{bmatrix}$

HWP, SA vertical $e^{-i\pi/2}\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$ HWP, SA horizontal $e^{i\pi/2}\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$

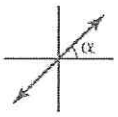
**III. Rotator**

Rotator $(\theta \rightarrow \theta + \beta)$ $\begin{bmatrix} \cos\beta & -\sin\beta \\ \sin\beta & \cos\beta \end{bmatrix}$

**Continued...**

# Summary of Jones Vectors

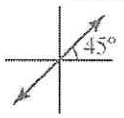
**I. Linear Polarization** ($\Delta\varphi = m\pi$)

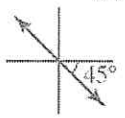
General: 


$$\tilde{\mathbf{E}}_0 = \begin{bmatrix} \cos\alpha \\ \sin\alpha \end{bmatrix}$$

Vertical: $\tilde{\mathbf{E}}_0 = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$

Horizontal: $\tilde{\mathbf{E}}_0 = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$

At + 45°: $\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ 1 \end{bmatrix}$ 


At −45°: $\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ -1 \end{bmatrix}$ 


**II. Circular Polarization** $\left(\Delta\phi = \frac{\pi}{2}\right)$

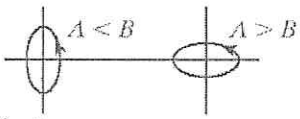
Left:

$$\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ i \end{bmatrix}$$

Right:

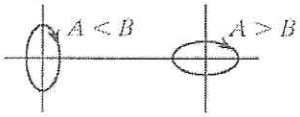
$$\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ -i \end{bmatrix}$$

**III. Elliptical Polarization**

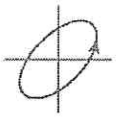
Left: 


$$\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{A^2 + B^2}}\begin{bmatrix} A \\ iB \end{bmatrix} \quad A > 0, B > 0$$

$(\Delta\phi = (m + 1/2)\,\pi)$

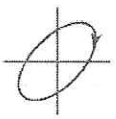
Right: 


$$\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{A^2 + B^2}}\begin{bmatrix} A \\ -iB \end{bmatrix} \quad A > 0, B > 0$$

Left: 

$$\tilde{\mathbf{E}}_0 \quad \frac{1}{\sqrt{A^2 + B^2 + C^2}}\begin{bmatrix} A \\ B + iC \end{bmatrix} \quad A > 0, C > 0$$

$\left(\Delta\phi \neq \begin{cases} m\pi \\ (m + 1/2)\pi \end{cases}\right)$

Right: 

$$\tilde{\mathbf{E}}_0 \quad \frac{1}{\sqrt{A^2 + B^2 + C^2}}\begin{bmatrix} A \\ B - iC \end{bmatrix} \quad A > 0, C > 0$$

**End of paper.**